ATTN: BOX PROVISIONAL PATENT APPLICATION
IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Provisional Application of

MIKI, Hisayuki; UDAGAWA, Takashi and OKUYAMA, Mineo

Provisional Application No.: 60/055,991

Filed: August 18, 1997

For: LIGHT-PERMEABLE ELECTRODE FOR LIGHT-EMITTING SEMICONDUCTOR DEVICES AND METHOD OF PRODUCING THE SAME

BOX PROVISIONAL PATENT APPLICATION
Attn: Office of National Application Review
Commisioner of Patents and Trademarks
Washington, D.C. 20231

SUBMISSIONS: SUBMISSION OF VERIFIED ENGLISH TRANSLATION; ENGLISH LANGUAGE VERIFIED TRANSLATION (29 PAGES + 5 SHEET OF DRAWINGS + EXECUTED TRANSLATOR'S DECLARATION) WITH ACCOMPANYING TRANSLATOR'S DECLARATION; **A CHECK FOR $ 130.00**; COPY OF NOTICE TO FILE MISSING PARTS OF PROVISIONAL APPLICATION FILED UNDER 37 CFR 1.53(B)(2) PETITION FOR EXTENSION OF TIME UNDER 37 C.F.R. § 1.136; **A CHECK FOR $110.00**

PLEASE STAMP AND RETURN TO
SUGHRUE, MION, ZINN, MACPEAK & SEAS
2100 Pennsylvania Avenue, N.W.
Washington, D.C. 20037
(202) 293-7060 BOX 79

Our Ref: P46482
Atty/Sec: WAB/gxm
Date: March 17, 1998

ATTN: BOX PROVISIONAL PATENT APPLICATION
IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Provisional Application of

MIKI, Hisayuki; UDAGAWA, Takashi and OKUYAMA, Mineo

Provisional Application No.: 60/055,991

Filed: August 18, 1997

For: LIGHT-PERMEABLE ELECTRODE FOR LIGHT-EMITTING SEMICONDUCTOR DEVICES AND METHOD OF PRODUCING THE SAME

SUBMISSION OF VERIFIED ENGLISH TRANSLATION

BOX PROVISIONAL PATENT APPLICATION
Attn: Office of National Application Review
Commissioner of Patents and Trademarks
Washington, D.C. 20231

Sir:

In response to the "Notice to File Missing Parts of Provisional Application Filed Under 37 CFR 1.53(b)(2)", mailed December 17, 1997, submitted herewith is the verified English language translation for the above-mentioned provisional application previously filed in the Japanese language. Also enclosed please find a Petition for Extension of Time Under 37 C.F.R. § 1.136.

Checks for the statutory fee of $130.00 and Petition for Extension of Time fee of $110.00 are attached. You are also directed and authorized to charge or credit any difference or overpayment to Deposit Account No. 19-4880. The Commissioner is hereby authorized to charge any fees under 37 C.F.R. 1.16 and 1.17 which may be required during the entire pendency of the provisional application to Deposit Account No. 19-4880. A duplicate copy of this transmittal letter is attached.

Respectfully submitted,

Waddell A. Biggart
Registration No. 24,861

SUGHRUE, MION, ZINN, MACPEAK & SEAS
2100 Pennsylvania Avenue, N.W.
Washington, D.C. 20037-3202
Tel: (202) 293-7060
WAB:gxm

Date: March 17, 1998

DECLARATION

I, Atsuko Ikeda, residing at 26-2-906, Ojima 3-chome, Koto-ku, Tokyo, Japan, do hereby certify that I am conversant with the English and Japanese languages and am a competent translator thereof. I further certify that to the best of my knowledge and belief the attached English translation is a true and correct translation made by me of U.S. Provisional Patent Application Serial No. 60/055,991 filed on August 18, 1997.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed this 6th day of March, 1998

Atsuko Ikeda

Atsuko Ikeda

[NAME OF DOCUMENT] Specification

[TITLE OF THE INVENTION]

Light-Permeable Electrode for Light-Emitting Semiconductor Devices and Method of Producing the Same

[SCOPE OF CLAIM FOR PATENT]

[Claim 1] A light-permeable electrode for light-emitting semiconductor devices, comprising a first layer formed to come into contact with the surface of a semiconductor and comprising at least one metal or an alloy of two or more metals, selected from the group consisting of Au, Pt, Pd, Ni, Al and Ti, which is light-permeable and capable of ohmic contact, and a second layer formed on said first layer and comprising a light-permeable metal oxide containing an oxide of at least one metal selected from Ni, Ti, Sn, Cr, Co, Zn, Cu, Mg and In.

[Claim 2] The light-permeable electrode for light-emitting semiconductor devices as claimed in claim 1, which comprises a first layer comprising Au and a second layer comprising an oxide of Ni.

[Claim 3] The light-permeable electrode for light-emitting semiconductor devices as claimed in claims 1 and 2, wherein the oxygen composition gradually decreases from the second layer toward the first layer in the region near the interface between said second layer and said first layer.

[Claim 4] The light-permeable electrode for light-emitting semiconductor devices as claimed in claims 1 to 3, wherein said first layer contains a metal element which is a main

component of the metal oxide constituting said second layer.

[Claim 5] The light-permeable electrode for light-emitting semiconductor devices as claimed in claims 1 to 4, wherein said first layer has a thickness of from 1 to 500 nm.

[Claim 6] The light-permeable electrode for light-emitting semiconductor devices as claimed in claims 1 to 5, wherein said second layer has a thickness of from 1 to 1,000 nm.

[Claim 7] The light-permeable electrode for light-emitting semiconductor devices as claimed in claims 1 to 6, wherein the semiconductor is a GaN-base compound semiconductor.

[Claim 8] A method of producing a light-permeable electrode for light-emitting semiconductor devices, comprising a first step for forming a first layer comprising a metal thin film, which is contacted with the surface of a semiconductor, light-permeable and capable of ohmic contact, a second step for forming a second layer comprising a metal on said first layer, and a third step for heat-treating the coating to oxidize said second layer.

[Claim 9] The method of producing a light-permeable electrode for light-emitting semiconductor devices as claimed in claim 8, wherein said first step and said second step are continuously performed in the same apparatus.

[Claim 10] The method of producing a light-permeable electrode for light-emitting semiconductor devices as claimed in claims 8 and 9, wherein said third step is performed in an atmosphere containing oxygen.

[Claim 11] The method of producing a light-permeable electrode for light-emitting semiconductor devices as claimed in claims 8 to 10, wherein the heat treatment in said third step is performed at a temperature of 300°C or higher for 1 minute or more.

[Claim 12] The method of producing a light-permeable electrode for light-emitting semiconductor devices as claimed in claims 8 to 11, wherein the semiconductor is a GaN-base compound semiconductor.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Technical Field to which the Invention belongs]

The present invention relates to an electrode for use in light-emitting semiconductor devices, more specifically, the present invention relates to a light-permeable electrode for light-permeable semiconductor devices and a method of producing the electrode.

[0002]

[Background Art]

In recent years, GaN-base compound semiconductor materials are drawing attention as a semiconductor material for light-emitting devices which emit short-wavelength light. The GaN-base compound semiconductor is formed on various oxide substrates such as sapphire single crystal or a III-V Group compound substrate by an organometallic vapor phase chemical reaction method (MOCVD method), a molecular beam epitaxy method (MBE method) or the like.

In the device using a substrate of an electrically insulating material, such as sapphire substrate, an electrode cannot be provided on the back surface of the substrate, differently from the III-V Group compound semiconductor material using a semiconductor substrate such as GaAs or GaP. Accordingly, a pair of positive and negative electrodes are necessary to be formed on the same surface of the light-emitting device.

[0003]

The GaN-base compound semiconductor material has a characteristic such that the current diffusion in the transverse direction is small. This is considered because a large number of transitions thrusting from the substrate to the surface are present in the epitaxial crystal, however, the reason is not yet elucidated.

Due to this characteristic, even when electrodes are formed and light is emitted by passing electricity therebetween, the light emission is limited to the region right under the electrode and the light difficultly diffuses to the peripheral region of the electrode. Since the light emission region is limited to the portion right under the electrode, in the case of conventional opaque electrodes, the light emission is interrupted by the electrode itself and cannot be taken out from the upside of the electrode. As a result, the light emission intensity is not improved as intended.

[0004]

In order to overcome the above-described problem, a

technique is disclosed with respect to the device structure (JP-A-6-314822 (the term "JP-A" as used herein means an "unexamined published Japanese patent application"), such that a light-permeable electrode comprising a very thin metal is used as a p-type electrode and formed almost on the entire front surface of the device to thereby take out the light emission from the upper side through the electrode.

According to this patent publication, for example, Au, Ni, Pt, In, Cr or Ti is used as the electrode material and the metal film evaporated is heat-treated at a temperature of 500°C or higher to cause sublimation of the metal, so that the thickness is reduced to from 0.001 to 1 μm and light permeability is imparted to the electrode.

[0005]

[Problems to be Solved by the Invention]

In the case of a light-permeable thin film using a metal, a metal film having a very small thickness is necessary to be formed. For example, in the case where Au is used as a light-permeable electrode and when light transmittance of 30% is intended, the film thickness must be adjusted to about 25 nm, and when light transmittance of 90% is intended to realize, the film thickness must be about 2 nm. In the case of Ni electrode, for realizing light transmittance of 30% or 90%, the film thickness must be about 13 nm or about 1.5 nm, respectively.

The term "light-permeable electrode" as used in the present invention means an electrode through which the light emission

generated under the electrode can be observed.

[0006]

In the production of a light-emitting semiconductor device, the metal electrode formed is necessary to be heat-treated so as to realize the ohmic contact in many cases.

However, in the case of an electrode using a very thin metal film as described above, a phenomenon called "ball up" where the metal coheres into a sphere occurs during the heat treatment performed for the purpose of achieving ohmic contact, because the surface tension of the metal surpasses the adhesion to the substrate. When the "ball up" occurs, the metal thin film causes crevices or cracks everywhere to lose the electrical continuity and no more functions as a light-permeable electrode.

[0007]

As a means to prevent the ball up, it is first considered to increase the thickness of the electrode comprising a metal. However, the increase in the thickness causes in turn reduction in the light transmittance and the electrode loses the light permeability.

The object of the present invention is to provide a light-permeable electrode for light-emitting semiconductor devices, having a structure capable of imparting light permeability and effectively preventing the ball up, and a method of producing the light-permeable electrode.

[0008]

[Means to Solve the Problems]

The present invention is a light-permeable electrode for light-emitting semiconductor devices, comprising a first layer formed to come into contact with the surface of a semiconductor and comprising at least one metal or an alloy of two or more metals selected from the group consisting of Au, Pt, Pd, Ni, Al and Ti, which is light-permeable and capable of ohmic contact, and a second layer formed on the first layer and comprising a light-permeable metal oxide containing an oxide of at least one metal selected from Ni, Ti, Sn, Cr, Co, Zn, Cu, Mg and In.

The present invention is characterized in that the above-described light-permeable electrode for light-emitting semiconductor devices comprises a first layer comprising Au and a second layer comprising an oxide of Ni.

[0009]

The present invention is further characterized in that in the above-described light-permeable electrode for light-emitting semiconductor devices, the oxygen composition gradually decreases from the second layer toward the first layer in the region near the interface between the second layer and the first layer.

The present invention is further characterized in that in the above-described light-permeable electrode for light-emitting semiconductor devices, the first layer contains a metal element which is a main component of the metal oxide constituting

the second layer.

[0010]

The present invention is further characterized in that in the above-described light-permeable electrode for light-emitting semiconductor devices, the first layer has a thickness of from 1 to 500 nm.

The present invention is further characterized in that in the above-described light-permeable electrode for light-emitting semiconductor devices, the second layer has a thickness of from 1 to 1,000 nm.

The present invention is further characterized in that in the above-described light-permeable electrode for light-emitting semiconductor devices, the semiconductor is a GaN-base compound semiconductor.

[0011]

Furthermore, the present invention provides a method of producing a light-permeable electrode for light-emitting semiconductor devices, comprising a first step for forming a first layer comprising a metal thin film, which is in contact with the surface of a semiconductor, light-permeable and capable of ohmic contact, a second step for forming a second layer comprising a metal on the first layer, and a third step of heat-treating the coating to oxidize the second layer.

[0012]

The present invention is further characterized in that in the above-described method of producing a light-permeable

electrode for light-emitting semiconductor devices, the first step and the second step are continuously performed in the same apparatus.

The present invention is further characterized in that in the above-described method of producing a light-permeable electrode for light-emitting semiconductor devices, the third step is performed in an atmosphere containing oxygen.

The present invention is further characterized in that in the above-described method of producing a light-permeable electrode for light-emitting semiconductor devices, the heat treatment in the third step is performed at a temperature of 300°C or higher for 1 minute or more.

The present invention is further characterized in that in the above-described method of producing a light-permeable electrode for light-emitting semiconductor devices, the semiconductor is a GaN-base compound semiconductor.

[0013]

[Mode for Carrying Out the Invention]

The light-permeable electrode for light-emitting semiconductor devices of the present invention comprises a first layer formed on the surface of a semiconductor and comprising a light-permeable metal, and a second layer formed on the first layer and comprising a light-permeable metal oxide.

In the case of a p-type semiconductor, the metal constituting the first layer formed to contact with the semiconductor may be selected from the metals which can attain good ohmic contact after

the heat treatment, such as Au, Pt, Pd and Ni. An alloy comprising a combination of at least two metals out of these metals may also be used.

Further, in order to attain good ohmic contact, an alloy obtained by adding a slight amount of at least one metal as an impurity, such as Zn, Ge, Sn, Be or Mg, to the above-described metal may be used.

In the case of an n-type semiconductor, the material constituting the first layer may be Al, Ti or Ni. An alloy comprising a combination of at least two metals out of these metals may also be used.

Further, in order to attain good ohmic contact, an alloy obtained by adding a slight amount of at least one metal as an impurity, such as Si, Ge, Sn, S or Se, to the above-described metal may be used.

[0014]

The metal oxide contained in the second layer is an oxide having relatively excellent light permeability and superior adhesive property to a metal, and an oxide of at least one metal selected from the group consisting of Ni, Ti, Sn, Cr, Co, Zn, Cu, Mg and In may be used. In particular, NiO, TiO, SnO, Cr_2O_3, CoO, ZnO, Cu_2O, MgO and In_2O_3, which are widely known to be light-permeable, and those mainly comprising an oxide where the above-described metal oxide and another metal element are present together, are useful. An oxide having good adhesive property to the backing metal is preferably selected.

The term "metal oxide" as used in the present invention means a mixture of oxides different in the oxidation number of the metals and includes the case where a metal not oxidized is contained. The second layer is characterized by the exercise of light permeability and accordingly, it is of course advantageous that the most light-permeable material out of oxides different in the composition is used as the main component.

This is described below by taking Ni as an example. Known oxides of Ni include NiO, Ni_2O_3, NiO_2 and Ni_3O_4. Any of these or a mixture thereof may be used as the composition of the material constituting the second layer. Or, Ni itself, which is a non-oxidized metal, may be contained. However, of these several kinds of oxides, NiO is known to exert most effectively the light permeability and a second layer comprising NiO as a main component is duly advantageous.

[0015]

The first layer comprising a metal and the second layer comprising a light-permeable metal oxide each preferably has good adhesive property.

To this effect, the light-permeable electrode for light-emitting semiconductor devices of the present invention preferably has a structure such that the oxygen composition gradually decreases from the second layer toward the first layer in the region near the interface between the second layer and the first layer. In other words, the composition preferably continuously changes from the composition containing a metal

oxide to the composition comprising a metal.

In order to attain high adhesion between the first layer and the second layer, the first layer preferably contains a metal component of the metal oxide contained in the second layer. The component of the second layer may be contained in the first layer in a constant concentration throughout the first layer or the concentration may have a gradient such that the concentration is reduced along the direction from the interface with the second layer toward the semiconductor surface. The component of the second layer may be contained in the entire of the first layer or may be contained only in a part of the interface side with the second layer.

[0016]

The first layer is preferably formed to have a thickness of from 1 to 500 nm so as to obtain light permeability. In particular, the layer thickness is preferably adjusted so as to attain a light transmittance calculated from the coefficient of absorption as a physical property value inherent to a metal, of from 10% to 90%.

The second layer preferably has a thickness of from 1 to 1,000 nm where light permeability is realized, excellent ball-up preventing effect is achieved and good light permeability is attained.

[0017]

The metal oxide for forming the second layer may be at least one metal oxide selected from the above-described light-permeable metal oxides, preferably from the group consisting of NiO, In_2O_3,

SnO, ZnO and MgO which are a metal oxide having electrical conductivity. An oxide containing two kinds of metal elements out of those contained in the above-described electrically conductive metal oxides, such as InSnO, may be used and a metal element other than the metal element contained in the above-described metal oxides may also be present together.

When such an electrically conductive metal oxide is used as the second layer for protecting the metal electrode layer of the first layer, the current can also pass through the protective layer part and the resistivity of the electrode as a whole is reduced. This reveals that the resistance between two electrodes in a device produced is decreased and a larger quantity of current can pass with the same voltage applied as compared with the case of using an insulator as the protective layer. As a result, a higher light emission intensity can be obtained with the same voltage.

[0018]

The above-described electrode can be formed by the method of forming a first layer comprising a metal and a second layer comprising a metal and performing heat treatment in an atmosphere containing oxygen to oxidize the second layer comprising a metal in the front surface side. The atmosphere containing oxygen means an atmosphere containing oxygen gas (O_2) or steam (H_2O).

[0019]

More specifically, the electrode for light-emitting semiconductor devices can be manufactured by forming a second

layer comprising a metal such as Ni, Ti, Sn, Cr, Co, Zn, Cu, Mg or Mn on the first layer comprising a metal and heat-treating the second layer at a temperature of 300°C or higher for 1 minute or more in an atmosphere containing oxygen.

The temperature and the time of heat treatment are necessary to be selected in accordance with the metal to be oxidized. According to the study by the present inventors, if the heat-treatment temperature is lower than 300°C, however longer the heat treatment is continued, the metals in general which can be used in the present invention cannot be completely and uniformly oxidized. On the other hand, as the heat-treatment temperature is higher, the metal can be oxidized more stably and therefore, any temperature of 300°C or higher may be used, however, of course, a temperature of not causing decomposition of the semiconductor should be selected.

Also, according to the study by the present inventors, if the heat-treatment time is less than 1 minute, however high temperature is selected from the above-described temperature range for the heat treatment, the metal cannot be completely and uniformly oxidized. Accordingly, the heat treatment is preferably performed for 1 minute or more.

The oxygen concentration in the atmosphere gas may be freely selected as long as it is not 0, however, the oxygen concentration is preferably 1 ppm or more.

[0020]

The heat treatment is also performed for diffusing the

component of the second layer into the first layer and this is effective to construct an electrode structure such that the component of the second layer is contained in the first layer. The heat treatment for oxidizing the second layer may be used at the same time as this heat treatment for diffusing the component of the second layer from the second layer into the first layer.

Further, the heat treatment for oxidizing the second layer may be served concurrently as the heat treatment for obtaining the ohmic contact between the semiconductor and the first layer comprising a metal. Or, the heat treatment for oxidizing the second layer and the heat treatment for obtaining the ohmic contact between the semiconductor and the first layer containing a metal may be performed separately.

[0021]

The metal film may be formed by the ordinary resistance heating deposition, electron beam heating deposition or sputtering.

The first layer and the second layer may be continuously formed in the same apparatus, or the first layer formed may be once taken out from the apparatus and the second layer may be formed thereon by another method. However, in view of the improvement in adhesion, the first layer and the second layer are preferably formed continuously in the same apparatus.

The electrode prepared by sequentially laminating a first layer and thereon a metal layer which becomes the second layer is a film having a dark color and presenting metal gloss, for

example, after the deposition, however, the metal layer which becomes the second layer is converted into a metal oxide due to oxidation during the heat treatment and exhibits light permeability.

[0022]

The metal layer and the metal oxide layer may have the same or different plane shape. However, needless to say, the metal layer part is more preferably covered with a metal oxide. The second layer comprising a metal oxide may completely overwhelm the first layer comprising a metal to provide a covered area larger than the first layer, however, it is not preferred for the second layer comprising a metal oxide to come into contact with the electrode in the opposite side. Since the metal oxide constituting the second layer may be an electrically conductive material, when an electrically conductive material is used for the second layer and the second layer is contacted with electrodes of both sides, the electrodes of both sides may be electrically connected through the second layer to cause leak of the current.

[0023]

The light-permeable electrode for light-emitting semiconductor devices according to the present invention and the production method thereof are particularly effective for the light-emitting semiconductor devices where the current diffusion from the electrode to the lateral side is small and the semiconductor is a GaN-base compound semiconductor. The GaN-base compound semiconductor can be generally represented by

AlGaInN.

[0024]

[Mode of Operation]

The electrode for light-emitting semiconductor devices according to the present invention comprises a first layer which has light permeability and comprises a metal thin film capable of ohmic contact with the semiconductor layer, and a second layer which has light permeability, inhibits ball up of the first layer at the heat treatment performed for realizing the ohmic contact between the first layer and the semiconductor layer and mainly comprises a metal oxide having light permeability. The second layer comprising a light-permeable metal oxide functions as the protective layer of the first layer. By using the second layer comprising a light-permeable metal oxide as the protective layer of the first layer comprising a metal, the ball up of the first layer can be prevented and a light-permeable electrode in the ohmic contact with a semiconductor can be stably produced.

Further, at the same time, by selecting a material having good adhesion to the first layer as the main component of the second layer, by providing a gradient in the oxygen composition between the second layer and the first layer or by diffusing the metal contained in the second layer into the first layer, the adhesion between the first layer and the second layer may be improved. Due to this structure improved in the adhesive property, occurrence of peeling off between the first layer comprising a metal and the second layer comprising a metal oxide can be effective prevented

and as a result, the light-emitting semiconductor device can be stably produced.

[0025]

According to the method for producing a light-permeable electrode for light-emitting semiconductor devices of the present invention, a first layer comprising a metal thin film capable of ohmic contact with a semiconductor and a metal layer which becomes the second after the heat treatment are formed, and the layers are heat-treated in an atmosphere containing oxygen, whereby the metal layer which becomes the second layer is converted into the second layer comprising a metal oxide and the light permeability is increased. In this manner, the light-permeable electrode can be easily produced. The heat treatment for oxidizing the metal layer which becomes the second layer can be used at the same time as the heat treatment for realizing the ohmic contact of the first layer.

[0026]

[Examples]

(Example 1)

Fig. 3 shows a cross-sectional view of one example of the light-permeable electrode for light-emitting semiconductor devices according to the present invention. In the electrode shown in Fig. 3, the semiconductor substrate 9 comprises a sapphire substrate having laminated thereon in sequence an n-type GaN layer, an InGaN layer, a p-type AlGaN layer and a p-type GaN layer with an AlN buffer layer. On the p-type GaN layer

thereof, a first layer 10 comprising Au and a second layer 11 comprising Ni oxide are formed. In Fig. 3, 7 is a p-side electrode bonding bad and 8 is an n-side electrode. Fig. 2 shows a plan view of the electrode for light-emitting semiconductor devices shown in Fig. 3 and the area shown by 6 is the light-permeable electrode according to the present invention.

[0027]

The light-permeable electrode for light-emitting semiconductor devices shown by Fig. 2 and Fig. 3 was produced through the following procedure.

First, the p-side electrode bonding pad 7 comprising an AuBe/Au layer structure was formed on the p-type GaN layer using a known photolithography technology.

Then, the first layer 10 comprising Au and the second layer 11 comprising Ni oxide were formed only in the region for forming the light-permeable electrode on the p-type GaN layer, by known photolithography technology and lift-off technology.

In the formation of the first layer 10 and the second layer 11, the semiconductor substrate 9 was placed in a vacuum evaporation machine and Au was evaporated on the p-type GaN layer at a pressure of 3×10^{-6} Torr to have a thickness of 25 nm and subsequently, Ni was deposited in the same vacuum chamber to have a thickness of 10 nm. The substrate having deposited thereon Au and Ni was taken out from the vacuum chamber and then treated through the lift-off procedure to form a thin film having a shape shown by 6 in Fig. 2. In this manner, a thin film comprising the

Au first layer and the Ni second layer was formed on the p-type GaN layer. The thin film formed had a dark gray color presenting metal gloss and scarcely exhibited light permeability.

The substrate was then heat treated in an annealing furnace at a temperature of 550°C for 10 minutes while flowing argon containing 1% of oxygen gas as the atmosphere gas. The light-permeable electrode 6 on the substrate taken out had a bluish dark gray color and exhibited light permeability. This heat treatment served concurrently as the heat treatment for obtaining the ohmic contact between the electrode and the semiconductor.

[0028]

The thus-produced light-permeable electrode had a transmittance of 45% for the light at a wavelength of 450 nm. The transmittance was measured using the same light-permeable electrode as above formed into a size for the measurement of transmittance.

The light-permeable electrode was also analyzed on the components in the depth direction using the Auger electron spectrum (AES). As a result, it was found that the thickness of the light-permeable electrode was not greatly changed between before and after the heat treatment but according to the Auger electron spectrum (AES), a large amount of oxygen was taken in into the second layer comprising Ni to cause oxidation of Ni. Fig. 1 shows the profile of respective elements in the depth direction of the electrode determined by AES.

It is seen from the profile of the electrode composition in the depth direction shown in Fig. 1 that the second layer comprises a Ni oxide containing Ni and oxygen, the first layer comprises Au slightly containing Ni, and a compositional gradient region is present in the region near the interface between the first layer and the second layer where the composition changes with a gradient such that the concentration of O reduces toward the substrate.

[0029]

The second layer 11 comprising an oxide of Ni was evaluated by the general thin film X-ray diffraction method (XRD) and found to have a spectrum as shown in Fig. 4. From the peak positions, peaks 12, 14, 16 and 18 are known to correspond to the diffraction from (111), (200), (220) and (311) faces of the NiO, respectively, revealing that the second layer 11 comprises crystals steering toward random directions of NiO. In this spectrum, a weak diffraction peak 15 from the (111) face of Ni was also detected. Further, diffraction peaks 13 and 17 from the Au (111) and (220) faces constituting the first layer 10 were also found. From these, a slight amount of Ni crystal grains seem to be mixed in the aggregate of the NiO crystal grains. Thus, it is verified that the second layer 11 comprises NiO and a slight amount of Ni.

[0030]

The n layer in the part for forming the n electrode was exposed by dry etching and in subsequent to the formation of the p-side electrode, the n-side electrode 8 comprising Al was formed on the exposed area and then heat treated for realizing ohmic contact

of the n-side electrode 8.

The wafer having formed thereon electrodes as above was cut into a chip of 400 μm square, mounted on a lead frame and connected to the lead to prepare a light emitting diode. The light emitting diode prepared exhibited an illumination output of 80 μW and a forward voltage of 3.2 V at a current of 20 mA. From a 2 inchϕ substrate, 16,000 chips were obtained and chips having an illumination strength of less than 76 μW were removed. As a result, the yield was 98%. The light-permeable electrode in the state of being electrified and illuminated was observed through a microscope. Then, the chips each showed uniform illumination of the light-permeable electrode and was not reduced in the illumination area due to ball up.

[0031]

(Example 2)

Fig. 6 shows a cross-sectional view of another example of the light-permeable electrode for light-emitting semiconductor devices according to the present invention. In the electrode shown in Fig. 6, the semiconductor substrate 9 comprises a sapphire substrate having laminated thereon in sequence a p-type GaN layer, a p-type AlGaN layer, an InGaN layer and an n-type GaN layer with an AlN buffer layer. On the n-type GaN layer thereof, a first layer 10 comprising Al and a second layer 11 comprising Ti oxide are formed. In Fig. 6, 7′ is a p-side electrode and 8′ is an n-side electrode bonding bad. Fig. 5 shows a plan view of the electrode for light-emitting semiconductor devices shown in

Fig. 6 and the area shown by 6 is the light-permeable electrode according to the present invention.

[0032]

The light-permeable electrode for light-emitting semiconductor devices shown by Fig. 5 and Fig. 6 was produced through the following procedure in the same manner as in Example 1.

First, the n-side electrode bonding bad 8' comprising Al was formed on the n-type GaN layer using a known photolithography technology.

Then, the first layer 10 comprising Al and the second layer 11 comprising Ti oxide were formed only in the region for forming the light-permeable electrode on the n-type GaN layer by known photolithography technology and lift-off technology.

In the formation of the first layer 10 and the second layer 11, the semiconductor substrate 9 was placed in a vacuum deposition machine and Al is deposited on the n-type GaN layer at a pressure of 3×10^{-6} Torr to have a thickness of 5 nm. The substrate was taken out from the deposition apparatus and subsequently, Ti was deposited in a separate deposition apparatus to have a thickness of 50 nm. The substrate having deposited thereon Al and Ti was taken out from the vacuum chamber and then treated through the lift-off procedure to form a thin film having a shape shown by 6 in Fig. 2. In this manner, a thin film comprising the Al first layer and the Ti second layer was formed on the n-type GaN layer. The thin film formed had a silver color

presenting metal gloss and scarcely exhibited light permeability.

The substrate was then heat treated in an annealing furnace at a temperature of 650°C for 15 minutes in an atmosphere of nitrogen gas containing 20% of oxygen. The thin film electrode part after the heat treatment was observed through an optical microscope and then found to have lost the metal gloss and show yellow-tinted light permeability. This heat treatment served concurrently as the heat treatment for obtaining the ohmic contact between the electrode and the semiconductor.

[0033]

The thus-produced light-permeable electrode was not changed in the thickness between before and after the heat treatment and the thin electrode part had a transmittance of 30% for the light at a wavelength of 450 nm. From the measurement results by AES and thin film XRD, the Ti layer was oxidized and turned into TiO.

The p-type layer was exposed by dry etching and the p-side electrode 7' comprising AuBe and Au was formed thereon in the same manner as in Example 1.

The resulting substrate was cut, mounted and connected to provide a light-emitting device. The light emitting diode prepared exhibited an illumination output of 80 μW and a forward voltage of 3.2 V at a current of 20 mA. From a 2 inchϕ substrate, 16,000 chips were obtained and chips having an illumination strength of less than 76 μW were removed. As a result, the yield was 96%. The chips each showed uniform illumination of the light-permeable electrode and had neither reduction in the

illumination area due to ball up nor ununiform illumination intensity.

[0034]

(Comparative Example 1)

On a semiconductor substrate having the same laminate structure as that in Example 1, a light-permeable electrode only comprising a single Au layer having a thickness of 25 nm was formed using an deposition apparatus. The substrate having formed thereon the Au layer was heat treated at 550°C for 10 minutes in an argon atmosphere for the purpose of realizing the ohmic contact with the p-GaN layer. After the heat treatment, the light-permeable electrode surface seemed to have increased in the light permeability but the metal gloss was lost. The light emitting diode produced from this semiconductor substrate was illuminated right under the electrode for bonding but the light-permeable electrode surface was not illuminated. On observation through an optical microscope, the Au thin layer formed as the light-permeable electrode was cohered into a ball shape and did not have continuity as a thin layer.

[0035]

(Comparative Example 2)

On a substrate having the same laminate structure as that in Example 1, a metal thin film electrode was formed by reversing the deposition order from that for the electrode prepared in Example 1, namely, Ni and subsequently Au were continuously formed to have a thickness of 10 nm and 25 nm, respectively. The

substrate having formed thereon the metal thin film electrode was then heat treated at 550°C for 10 minutes in an argon gas atmosphere containing 1% of oxygen. The depth-direction profile of the electrode by AES is shown in Fig. 7. A significant amount of oxygen was not detected and therefore, it was verified that the Ni layer was not oxidized. This seems to have occurred because the surface was covered by Au. The electrode had slight light permeability but it presented a gold color with metal gloss and the transmission was low and 10%.

A light emitting diode was prepared using the thin film electrode formed through the above-described procedure. The forward voltage at 20 mA of the light emitting diode was 3.0 on average and the same as that in Example 1 but the illumination intensity was 20 μW and extremely smaller than that in Example 1.

[0036]

[Effects of the Invention]

According to the present invention, a light-permeable electrode for light-emitting semiconductor devices, having light permeability and a structure capable of effectively preventing the ball up, and a method of producing the light-permeable electrode can be provided.

[0037]

The present invention is by no means limited the above-described two Examples, but for example, Pt, Ni or Pt may be used as the first layer for the p-type semiconductor and Ti, Al or Ni

may be used as the first layer for the n-type semiconductor. Further, an oxide layer containing a metal such as Co, Sn, Cr, Zn, Cu, Mg or In may be used as the second layer.

Furthermore, other than GaN described in the Examples, GaAs, GaP, InGaAs or AlInGaP may be used as the semiconductor material which is formed into a light-emitting device.

[BRIEF DESCRIPTION OF DRAWINGS]

[Fig. 1]

Fig. 1 is a view showing the depth-direction profile of respective elements by the Auger electron spectrum of the electrode produced in Example 1.

[Fig. 2]

Fig. 2 is a plan view showing the shape of the electrode produced in Example 1.

[Fig. 3]

Fig. 3 is a cross section showing the laminate structure of the electrode produced in Example 1.

[Fig. 4]

Fig. 4 is a thin film XRD spectrum of the electrode produced in Example 1.

[Fig. 5]

Fig. 5 is a plan view showing the shape of the electrode produced in Example 2.

[Fig. 6]

Fig. 6 is a cross section showing the laminate structure of the electrode produced in Example 2.

[Fig. 7]

Fig. 7 is a view showing the depth-direction profile of respective elements by the Auger electron spectrum of the electrode produced in Comparative Example 2.

[Description of Reference Numerals]

1 ... profile of Ni

2 ... profile of Au

3 ... profile of O

4 ... profile of Ga

5 ... profile of N

6 ... light-permeable electrode

7 ... p-side electrode bonding pad

7′ ... p-side electrode

8 ... n-side electrode

8′ ... n-side electrode bonding pad

9 ... semiconductor substrate

10 ... first layer

11 ... second layer

12 ... peak of NiO (111)

13 ... peak of Au (111)

14 ... peak of NiO (200)

15 ... peak of Ni (111)

16 ... peak of NiO (220)

17 ... peak of Au (220)

18 ... peak of NiO (311)

[NAME OF THE DOCUMENT] Abstract

[SUMMARY]

[PROBLEM TO BE SOLVED]

To provide a light-permeable electrode for light-emitting semiconductor devices, having light permeability and a structure capable of effectively preventing the ball up, and a method of producing the light-permeable electrode

[MEANS TO SOLVE THE PROBLEM]

The light-permeable electrode for light-emitting semiconductor devices according to the present invention comprises a first layer formed to come into contact with the surface of a semiconductor and comprising at least one metal or an alloy of two or more metals, selected from the group consisting of Au, Pt, Pd, Ni, Al and Ti, which is light-permeable and capable of ohmic contact, and a second layer formed on said first layer and comprising a light-permeable metal oxide containing an oxide of at least one metal selected from Ni, Ti, Sn, Cr, Co, Zn, Cu, Mg and In.

[SELECTED DRAWING] Fig. 1.